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Hydro Plant Risk Assessment Guide

Chapter xx: Excitation System Condition Assessment

xx.1 GENERAL

Excitation systems are key components in hydroelectric powerplants and are appropriate for analysis under a risk assessment program. Excitation system failure can have a significant economic impact due to high equipment costs as well as long lead times in procurement, manufacturing, and installation.

An excitation system can be divided into two major subsystems: the low voltage system (control and electronics) and the high voltage system (excitation system supply transformer, rotating exciter, power bridge, supply breaker, field breaker, etc.). The high voltage portion of the excitation system will likely dictate the need for replacement of the entire system. The low voltage and electronic portion will play a key role if spare parts are no longer available and/or the equipment becomes obsolete. A failure of one or more components in a system may not necessitate the replacement of the entire system, only the affected components.

Many excitation system abnormalities, especially in the low voltage control portion, are readily detected through regular maintenance and can be corrected without complete replacement of the excitation system. Individual electronic circuits can be replaced efficiently and cheaply if they are still supported by the manufacturer. However, if manufacturer support is not available then the costs may become substantial and a partial or complete replacement of the excitation system may be warranted.

Determining the existing condition of an excitation system is an essential step in analyzing the risk of failure. This guide provides a process for arriving at an Excitation System Condition Index. This condition index may be used as an input to the risk-based economic analysis model. The output of the economic analysis is a set of alternative scenarios, including costs and benefits, intended to guide asset management decisions on replacement or rehabilitation.

xx.2 SCOPE / APPLICATION

The excitation system condition assessment methodology outlined in this guide applies to fully static systems (SCR bridge rectifier supplying the required generator field voltage), rotating exciter systems incorporating electronic regulators and/or pilot exciters, and older magnetic amplifier type systems.

This guide is not intended to define excitation system maintenance practices or describe in detail excitation system condition assessment inspections, tests, or measurements. Utility maintenance policies and procedures must be consulted for such information.

xx.3 CONDITION INDICATORS AND EXCITATION SYSTEM CONDITION INDEX

This guide describes five Condition Indicators generally regarded by engineers as providing a sound basis for assessing excitation system condition:

- Age
- Operation and Maintenance History
- Availability of Spare Parts
- Power Circuitry Tests (excitation supply transformer, rotating exciter, rectifier bridge, AC and DC circuit breakers, etc.)
- Control Circuitry Tests (electronic circuits, power supplies, control logic, etc.)

These indicators are based on "Tier 1" inspections, tests, and measurements conducted by utility staff or contractors over the course of time. The indicators are assigned a numerical score and are used to arrive at an overall Excitation System Condition Index.

An additional stand-alone indicator is used to reflect the quality of the information available for scoring the Excitation System Condition Index. In some cases, data may be missing, out-of-date, or of questionable integrity. Any of these situations could affect the validity of the overall Condition Index. Given the potential impact of poor or missing data, a Data Quality Indicator is rated as a means of evaluating and recording confidence in the final Excitation System Condition Index.

The guide also describes Tier 2 tests that may be applied to excitation systems depending on utility practice. Tier 2 tests are considered non-routine. However, if Tier 2 data is readily available, it may be used to supplement the Tier 1 assessment. Alternatively, Tier 2 tests may be deliberately performed to address Tier 1 findings. Results of the Tier 2 analysis may either increase or decrease the score of the Excitation System Condition Index. The Data Quality Indicator score may also be revised during the Tier 2 assessment to reflect the availability of additional information or test data.

After review by an excitation system expert, the Condition Index is suitable for use as an input to the risk and economic analysis model.

Note: A severely negative result of ANY inspection, test, or measurement may be adequate in itself to require immediate de-energization, or prevent re-energization, of the excitation system regardless of the Excitation System Condition Index score.

xx.4 INSPECTIONS, TESTING, AND MEASUREMENTS

Inspections, tests, and measurements performed to determine Excitation System condition are divided into two tiers or levels. Tier 1 tests are those that are routinely accomplished as part of normal operation and maintenance or are readily available by examination of existing data. Results of Tier 1 tests are quantified as Condition Indicator Scores, and are then weighted and summed to arrive at an Excitation System Condition Index. Tier 1 tests may indicate abnormal conditions that can be resolved via standard corrective maintenance solutions. To the extent that Tier 1 tests result in immediate corrective maintenance actions being taken by plant staff, appropriate adjustments to the condition indicator scores should be reflected and the new results used when computing the overall Condition Index.

Tier 1 test results may indicate the need for further, non-routine evaluation, categorized as Tier 2 tests that may be applied to assess the specific problem being investigated. The Tier 2 analysis may be used to modify the score of the Excitation System Condition Index established using Tier 1 tests and may also confirm or disprove the need for more extensive maintenance, rehabilitation, or replacement.

Inspection, testing, and measurement methods are specified in technical references specific to the electric utility. This guide assumes that Tier 1 and Tier 2 inspections, tests, and measurements are conducted and analyzed by staff suitably trained and experienced in excitation system diagnostics. Qualified local staff members may perform some basic tests. More complex inspections and measurements may require an excitation system diagnostics “expert”.

This guide also assumes that inspections, tests, and measurements are conducted on a frequency that provides accurate and current information needed by the assessment. In some cases, it may be necessary to conduct tests prior to this assessment to acquire current data.

Excitation system condition assessment may cause concern that justifies more frequent monitoring. Utilities should consider the possibility of installing an on-line monitoring system that will continuously track critical quantities. This will provide additional data for condition assessment and establish a certain amount of reassurance as excitation system alternatives are being explored.

xx.5 SCORING

Excitation System Condition Indicator scoring is somewhat subjective, relying on excitation system condition experts. Relative terms such as “Results Normal” and “Degradation” refer to results that are compared to industry accepted levels; or to baseline or previous (acceptable) levels on this equipment; or to equipment of similar design, construction, or age operating in a similar environment.

xx.6 WEIGHTING FACTORS

Weighting factors used in the condition assessment methodology recognize that some Condition Indicators may affect the Excitation System Condition Index to a greater or lesser degree than

other indicators. These weighting factors were arrived at by consensus among excitation system design and maintenance personnel with extensive experience.

xx.7 MITIGATING FACTORS

Every excitation system is unique and therefore the methodology described in this guide cannot quantify all factors that affect individual excitation system condition. It is important that the Excitation System Condition Index arrived at be scrutinized by engineering experts. Mitigating factors specific to the utility may determine the final Condition Index and the final decision on excitation system replacement.

xx.8 DOCUMENTATION

Substantiating documentation is essential to support findings of the assessment, particularly where a Tier 1 Condition Indicator score is less than 3 or where a Tier 2 test results in subtractions from the Excitation System Condition Index. Test results and reports, photographs, O&M records, or other documentation should accompany the Excitation System Condition Assessment Summary Form.

xx.9 CONDITION ASSESSMENT METHODOLOGY

The condition assessment methodology consists of analyzing each Condition Indicator individually to arrive at a Condition Indicator Score. The score is then weighted and summed with scores from other condition indicators to determine the Excitation System Condition Index. The Condition Index is applied to the Excitation System Condition-Based Alternatives table (Table 8) to determine the recommended course of action.

Reasonable efforts should be made to perform Tier 1 inspections, tests, and measurements. However, when data is missing to properly score the Condition Indicator, it may be assumed that the score is "Good" or numerically some mid-range number such as 2. Caution: This strategy should be used judiciously to prevent misleading results. In recognition of the potential impact of poor or missing data, a separate Data Quality Indicator is rated as a means of evaluating and recording confidence in the final Excitation System Condition Index.

xx.10 TIER 1 - INSPECTIONS, TESTS, MEASUREMENTS

Condition Indicator 1 - Age

During operation, excitation systems are continuously subjected to electrical, mechanical, thermal, and environmental stresses. Over time, these stresses act and interact in complex ways to deteriorate certain components in the excitation system and possibly leading to unexpected, catastrophic failure and forced outage.

Age is one indicator of remaining life of the excitation system and is an important factor to consider when identifying candidates for replacement. The average life expectancy of previous excitation systems was about 30 years. However, it is difficult to predict life expectancy for newer digital systems where computer software/hardware may become obsolete in a few years and long-term experience with digital systems is not yet available. Accordingly, comparisons to average equipment age industry-wide may be of value.

While age is a useful indicator of remaining life and upgrade potential, it is also important to recognize that the actual service life that can be realized varies widely depending on the specific manufacturer, date of manufacture, design, materials, production methods, quality of installation, material in the supply transformer and cables, and the operation and maintenance history.

Qualified personnel should make a determination of scoring that encompasses as many aging factors as possible under this indicator. Results are analyzed and applied to Table 1 to arrive at a Condition Indicator Score.

Table 1 - Age Scoring

Age	Condition Indicator Score
Less than 10 years	2
10 to 20 years	1
20 to 30 years	0
30 to 40 years	-3
Over 40 years	-4

Condition Indicator 2 - Operation and Maintenance History

Operation and maintenance (O&M) history may indicate overall excitation system condition. O&M history factors that may apply are listed below. Depending on the age of the excitation system, some of the following items may not be applicable:

- Motor operated adjuster (motor and potentiometer condition)
- Supply transformer maintenance history
- Power bridge maintenance history
- Circuit breakers (AC supply and DC field breakers) maintenance history
- Premature component failures
- Abnormally high temperatures in supply transformer (via infrared scanning)
- Abnormally high temperatures in power bridge (via infrared scanning)
- Abnormally high temperatures in bus bar connections (via infrared scanning)
- Commutator pitting and/or premature brush failure
- Problems with auxiliary systems (airflow sensors, fans, control relays, etc.)

- Deteriorated control and protection wiring and devices
- Increase in corrective maintenance or difficulty in acquiring spare parts
- Anomalies determined by physical inspection
- Previous failures on this equipment
- Known failures or problems with equipment of similar design, construction, or age occurring on adjacent units or in other plants
- Frequent diagnostic or failure alarms or tripping

Qualified personnel should make a subjective determination of scoring that encompasses as many operation and maintenance factors as possible under this indicator. Results are analyzed and applied to Table 2 to arrive at a Condition Indicator Score.

Table 2 - Operation and Maintenance History Scoring

Results	Condition Indicator Score
Operation and Maintenance are normal.	2
Some additional maintenance above normal occurring.	1
Significant additional maintenance is required; or forced outage or unit trip occurs; or outages are regularly extended due to maintenance problems; or similar units are problematic.	-2
Repeated forced outages; maintenance not cost effective; or severe mechanical/electrical problems; or similar units have failed.	-4

Condition Indicator 3 – Availability of Spare Parts

Excitation systems consist of a large number of components and many spare parts are purchased when the systems are purchased and installed. In addition to the spare parts stored on the premises, the availability of replacement parts from the manufacturer is an important consideration. This applies particularly to electronic components, which tend to have short production life spans.

A variety of factors may be considered when evaluating the availability of spare parts, such as the level of impact a component may have on the operation of the excitation system. Limited operation may be possible upon failure of some components, whereas others may be critical to operation. Peripheral systems necessary to program or diagnose digital systems should also be considered. Becasue computer software has a short life span, compatibility becomes difficult over time, and hardware and software standards become obsolete. Qualified personnel should make a determination of scoring that encompasses as many factors as possible under this indicator. Results are analyzed and applied to Table 3 to arrive at a Condition Indicator Score.

Table 3 - Availability of Spare Parts Scoring	
Results	**Condition Indicator Score**
Spare parts are readily available.	2
Some spare parts are not readily available, but are still in production.	0
Some spare parts are not readily available or in production, but can be obtained on a limited basis or reproduced.	-1
Spare parts are unavailable.	-3

Condition Indicator 4 - Power Circuitry Tests

Elements of the power circuit consist of various combinations of power transformers, DC or AC generators, amplidynes, circuit breakers, power cables, rectifier bridges, field flashing equipment, etc. Requirements for many of the elements will be included in standard plant equipment maintenance documents. For example, maintenance, performance, repair, or replacement schedules are usually specified in manufacturer's instruction and maintenance manuals. In cases where elements are found to be deficient, repair or replacement of a single component may be the most appropriate solution, although replacement of other components or entire systems may sometimes be appropriate.

Qualified personnel should make a determination of scoring that encompasses as many factors as possible under this indicator. Results are analyzed and applied to Table 4 to arrive at a Condition Indicator Score.

Table 4 – Power Circuitry Scoring	
Results	**Condition Indicator Score**
Power circuit elements are normal.	2
One power circuit element assessment indicates minor deficiencies.	-1
More than one minor deficiency in power circuit.	-2
Severe power circuit component deficiency.	-5

Condition Indicator 5 - Control Circuitry Tests

Elements of the control circuit consist of various combinations of electronics, power supplies, control logic, relays, digital controllers, magnetic amplifiers, etc. In most cases, replacement of a

single problematic component may be the most appropriate solution, although replacement of other components or entire systems may be necessary, depending on the level of integration versus modularity.

Excitation system control circuits incorporate many critical functions of the generator operation, such as voltage regulation, limiters and protective functions, stabilizers, etc. Different components may have varying impacts on the operation of the excitation system. For example, limited operation may be possible upon failure of some components, whereas others may prevent operation of the generator. In fact, problems in excitation system control circuits are likely to manifest as generator misoperations.

Thorough evaluation of control circuitry will likely have to be conducted by specialists, although it may be standard operating practice (possibly reinforced by national and/or regional reliability council requirements) to perform specialized, detailed testing of these systems on a periodic basis. The most current reports of such required tests may be valuable in this assessment. Attention should also be paid to whether the excitation system meets the stability requirements specified by the reliability councils, etc. More detailed testing of excitation systems is listed as a Tier 2 assessment.

Qualified personnel should make a determination of scoring that encompasses as many factors as possible under this indicator. Results are analyzed and applied to Table 5 to arrive at a Condition Indicator Score.

Table 5 – Control Circuitry Scoring

Results	Condition Indicator Score
Control circuitry is functioning normally, stability requirements met.	2
Minor variations in functionality, stability requirements met.	1
Major variations in functionality, or stability performance marginal.	-2
Elements of control circuits are non-functional, or stability requirements not met.	-5

xx.11 TIER 1 – EXCITATION SYSTEM CONDITION INDEX CALCULATIONS

Enter the Condition Indicator Scores from the tables above into the Excitation System Condition Assessment Summary form at the end of this guide. Multiply each condition indicator score by its corresponding Weighting Factor, and sum the Total Scores to arrive at the Tier 1 Excitation System Condition Index. If the result yields a negative value, set the Condition Index score to zero. Suggested alternatives for follow up action, based on the Excitation System Condition Index, are described in the Excitation System Condition-Based Alternatives at the end of this guide.

xx.12 TIER 1 –DATA QUALITY INDICATOR

Data Quality Indicator – Quality of Inspections, Tests and Measurements

The Data Quality Indicator reflects the quality of the inspection, test and measurement results used to evaluate the condition of the excitation system. The more current and complete the results are, the higher the rating for this indicator. The normal testing frequency is defined as the organization's recommended frequency for performing the specific test or inspection.

Qualified personnel should make a determination of scoring that encompasses as many factors as possible under this indicator. Results are analyzed and applied to Table 6 to arrive at an appropriate Data Quality Indicator Score.

Table 6 –Data Quality Scoring

Results	Data Quality Indicator Score
All Tier 1 inspections, tests and measurements were completed within the normal testing frequency.	10
One or more of the Tier 1 inspections, tests and measurements were completed between 6 and 24 months past the normal testing frequency.	7
One or more of the Tier 1 inspections, tests and measurements were completed between 24 and 36 months past the normal testing frequency, or some of the results are not available.	4
One or more of the Tier 1 inspections, tests and measurements were completed more than 36 months past the normal frequency, or no results are available.	0

xx.13 TIER 2 - INSPECTIONS, TESTS, MEASUREMENTS

Tier 2 inspections, tests, and measurements generally require specialized equipment or training, may be intrusive, or may require an extended outage to perform. Tier 2 assessment is considered non-routine. Tier 2 inspections may affect the Excitation System Condition Index number established using Tier 1 and also may confirm or disprove the need for more extensive maintenance, rehabilitation, or excitation system replacement.

Test T2.1: Detailed Control Circuitry Tests (Excitation System Realignment)

An excitation system realignment is performed by excitation system specialists and includes detailed testing of most excitation system functions, such as regulators, limiters, protection, control functions, stability, etc.

Results are analyzed and applied to Table 7 to arrive at an Excitation System Condition Index score adjustment.

Table 7 - Detailed Control Circuitry Test Scoring

Test Results	Adjustment to Excitation System Condition Index
Excitation system is fully operational with no significant functional abnormalities. Some readjustment may be necessary.	No Change
Excitation system is operational, but abnormalities are detected. Significant adjustment or repair is necessary.	Subtract 1.0
Excitation system has components that are not operational.	May indicate a serious problem requiring immediate evaluation. Generator and power system reliability may be compromised.

Test T2.2: Other Specialized Diagnostic Tests

Additional tests may be applied to evaluate specific excitation system problems. Some of these diagnostic tests may be considered to be of an investigative research nature. When conclusive results from other diagnostic tests are available, they may be used to make an appropriate adjustment to the Excitation System Condition Index.

xx.14 TIER 2 – EXCITATION SYSTEM CONDITION INDEX CALCULATIONS

Enter the Tier 2 adjustments from the tables above into the Excitation System Condition Assessment Summary form at the end of this guide. Subtract the sum of these adjustments from the Tier 1 Excitation System Condition Index to arrive at the Net Excitation System Condition Index. If the result yields a negative value, set the Condition Index score to zero. Attach supporting documentation. An adjustment to the Data Quality Indicator score may be appropriate if additional information or test results were obtained during the Tier 2 assessment.

xx.15 EXCITATION SYSTEM CONDITION-BASED ALTERNATIVES

After review by an excitation system expert, the Excitation System Condition Index - either modified by Tier 2 tests or not - may be sufficient for decision making regarding excitation system alternatives. The Index is also suitable for use in the risk-based economic analysis

model. Where it is desired to consider alternatives based solely on excitation system condition, the Excitation System Condition Index may be directly applied to Table 8.

Table 8 - Generator Condition-Based Alternatives

Excitation System Condition Index	Suggested Course of Action
≥ 7.0 and ≤ 10 (Good)	Continue O&M without restriction. Repeat condition assessment as needed.
≥ 3.0 and < 7 (Fair)	Continue operation but reevaluate O&M practices. Consider using appropriate Tier 2 tests. Repeat condition assessment process as needed.
≥ 0 and < 3.0 (Poor)	Immediate evaluation including additional Tier 2 testing. Consultation with experts. Adjust O&M as prudent. Begin replacement/rehabilitation process.

EXCITATION SYSTEM
TIER 1 CONDITION ASSESSMENT SUMMARY

Date: _____ Excitation System Identifier: _____

Location: _____ Manufacturer: _____ Yr. Mfd. _____

No. of Phases: _____ MVA: _____ Voltage: _____

Tier 1 Excitation System Condition Summary
(For instructions on indicator scoring, please refer to condition assessment guide)

No.	Condition Indicator	Score ×	Weighting Factor =	Total Score
1	**Age** *(Score must be 0, 1, 2,, 3, or 4)*		1	
2	**O&M History** *(Score must be 0, 1, 2, or 3)*		1	
3	**Availability of Spare Parts** *(Score must be 0, 1, 2, or 3)*		1	
4	**Power Circuitry Tests** *(Score must be 0, 1, 2, or 3)*		1	
5	**Control Circuitry Tests** *(Score must be 0, 1, 2, or 3)*		1	
Excitation System Condition Index (Sum of individual Total Scores) *(Condition Index should be between 0 and 10)*				

Data Quality Indicator *(Value must be 0, 4, 7, or 10)*	

Evaluator: _____ Technical Review: _____

Management Review: _____ Copies to: _____

EXCITATION SYSTEM
TIER 2 CONDITION ASSESSMENT SUMMARY

Tier 2 Excitation System Condition Summary		
No.	**Tier 2 Test**	**Adjustment to Tier 1 Condition Index**
T2.1	**Detailed Control Circuitry Test**	
T2.2	**Other Specialized Diagnostic Tests**	
Tier 2 Adjustments to Excitation System Condition Index (Sum of individual Adjustments)		

Data Quality Indicator *(Value must be 0, 4, 7, or 10)*	

To calculate the net Excitation System Condition Index, subtract the Tier 2 Adjustments from the Tier 1 Condition Index:

Tier 1 Excitation System Condition Index _____

minus **Tier 2 Adjustments** _____ = _____

Net Excitation System Condition Index

Evaluator(s): _____ Date: _____

Technical Reviewer: _____ Management Review: _____

Copies to: _____

(Attach supporting documentation.)